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Brief Article

Can Emotional Content Reduce the Age Gap in Visual Working Memory? Evidence from Two Tasks

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Abstract

Aging is associated with declines in several cognitive abilities including working memory (WM). The goal of the present study was to assess whether emotional information could reduce the age gap in the quantity and quality (precision) of representations in visual WM. Young and older adults completed a Serial Image Recognition (SIR) task and a Color-Image Binding (CIB) task. Results of the SIR task showed worse performance for negative than neutral and positive images within the older group, hence enlarging the age gap in WM. In the CIB task, recall precision was lower in the old than young adults, showing an aging decline in the quality of WM representations. Positive images tended to improve precision, but this boost was similar for both age groups. In sum, emotional content did not reduce the age gap in visual WM.

Key-words: visual working memory, emotion, aging, memory precision, valence.

Can Emotional Content Reduce the Age Gap in Visual Working Memory? Evidence from Two Tasks

Aging is associated with declines in working memory (WM) performance (Salthouse & Babcock, 1991). WM is the system maintaining representations temporarily accessible for ongoing cognitive processing. The goal of the present study was to assess whether processing of emotional information can reduce the age gap in WM. To the best of our knowledge, only five studies assessed age differences in WM tasks with neutral and emotional content. Three studies tested verbal WM. Mammarella, Borella, Carretti, Leonardi, and Fairfield (2013) found decreasing WM performance as a function of age when comparing groups of young, young-old, and old-old adults in a WM span task with neutral words. Presenting positive words enhanced WM of young-old and old-old adults, leading to similar performance levels when comparing young and young-old adults. Negative words enhanced performance of all participants, but more so for the older adults thereby nullifying age differences. Borella, Carretti, Grassi, Nucci, and Sciori (2014) found that negative words were better recalled than positive words, which in turn were better recalled than neutral ones. In contrast to Mammarella et al., emotion boosted memory similarly for young and old adults, retaining the age gap. Truong and Yang (2014) also found that positive and negative words were better recognized than neutral words by both young and old adults. This study, however, failed to find age impairments on WM perhaps due to the small memory load in their task that led to ceiling effects.

Two other studies tested visual WM. Mikels, Larkin, Reuter-Lorenz, and Carstensen (2005) found that visual WM for the emotional intensity of images, but not for their brightness, was unimpaired in old adults compared to young adults. Moreover, old adults showed superior WM for positive relative to negative images, whereas the young exhibited the opposite pattern.

Lastly, Borg, Leroy, Favre, Laurent, and Thomas-Antérion (2011) assessed age effects in an image task and image-location binding task with negative and neutral images. Young adults outperformed the old adults in both tasks. Negative pictures boosted performance in the image task to a similar extent for both groups, hence maintaining the age gap. In contrast, negative images impaired performance of only the old adults in the binding task.

In sum, the scarce, extant literature is inconsistent regarding the effects of emotion on WM in old age: two studies showed a larger beneficial effect of emotion in old age than in young adulthood, in three studies the emotional enhancement was of similar magnitude for both age groups, and in one case a detrimental emotional effect on binding in old age was reported. These divergent findings reflect the heterogeneity of emotion-related effects on WM observed in studies with young adults: Both enhancement (González-Garrido, López-Franco, Gómez-Velázquez, Ramos-Loyo, & Sequeira, 2015; Jackson, Linden, & Raymond, 2014) and impairments (Fairfield, Mammarella, Di Domenico, & Palumbo, 2015; Kensinger & Corkin, 2003) have been reported. Given this stand, it is clear that more research is needed to identify whether, and under which conditions, emotional content influences WM and whether it can reduce the impact of age-related WM impairments.

There are a number of mechanisms through which emotion could modulate WM, which in turn would lend differential opportunities for age to moderate this effect. First, WM depends critically on attention during both encoding and maintenance (Gazzaley & Nobre, 2012). Emotion could increase attention during encoding (Murty, Ritchey, Adcock, & LaBar, 2010). It follows that emotion would be particularly helpful when neutral and emotionally-charged items are presented concurrently (mixed-valence trials) than when all items have the same valence (Watts, Buratto, Brotherhood, Barnacle, & Schaefer, 2014). Moreover, if older adults are more prone to lose sustained attention during encoding, then emotional content might be particularly helpful for them.

Second, emotion may influence how visual WM resources are allocated, without changing overall WM capacity. Emotion may lead participants to prioritize representational quality at the expense of quantity, or the converse. Spachtholz, Kuhbander, and Pekrun (2014) reported that negative mood increased the quality of visual WM representations at the cost of the quantity of stored items compared to neutral mood, hence showing a quantity-quality trade-off. This study, however, assessed emotional state instead of emotional content, and only in young adults. Some studies have suggested that old adults are biased towards positive information, whereas young adults are biased towards negative information (Mather, 2012). If this is the case, young and old adults may show different trade-offs as a function of valence.

A third possibility is that emotion allows participants to boost the efficiency of cognitive processing. This hypothesis predicts no quantity-quality trade-off, but an overall increase on WM capacity (i.e., increase in quality with no change in quantity, or vice-versa). Consistent with this possibility, Xie and Zhang (2016) observed a boost in the quality of WM representations under negative mood (compared to neutral and positive states),with no change in the quantity of items stored in WM in a sample of young adults. Given that processing is likely to be overall less efficient in older than young adults, older adults might benefit more from an emotional boosting to their cognitive functioning, thereby reducing the age gap.

In the present study, we assessed for these possibilities by asking young and old adults to complete two visual WM tasks with emotional content (positive and negative images compared to neutral ones). One task required serial order memory for a sequence of pictures (SIR task). This task measures the quantity of stored representations, without putting large demands on representational quality (which may change without affecting performance). The other task required memory for image-color bindings (CIB task): the image served as a cue to reproduce a continuous color using a color wheel. In this task, representational quantity (number of stored items) and quality (the fidelity of the stored color) contribute to performance. The assessment of differential impact of emotion across the two tasks is informative regarding putative quantity-quality changes and trade-offs as a function of emotion. The SIR task can assess changes in quantity, whereas the CIB task is sensitive to changes in quantity and quality. If emotion only impacts WM quality, then only the CIB task should show valence effects. Boosts or costs on quantity with no effect on quality should affect performance in the SIR and CIB task alike. If, however, quantity changes at the expense of quality, emotion effects in the two tasks will diverge. Moreover, we included mixed-valence and single-valence trials in both tasks. If emotion simply draws attention during encoding hence biasing people away from neutral content, one may observe valence effects only in mixed-valence trials. If emotion changes strategic allocation of WM resources or boosts WM overall, valence should impact performance in both types of trials.

Method

Participants

The sample comprised 24 young (*M* = 26.17 years, 37.5% men) and 24 older adults (*M* = 70.96 years, 54.2% men). Exclusion criteria were color blindness, phobias or increased sensibility towards certain stimuli, and a history of alcohol or drug dependency. Older participants scored at least 26 (cut-off score) in the Mini-Mental-Status Test (Folstein, Folstein, & McHugh, 1975; *M* = 28.58, *SD* = 1.06), thus showing no signs of cognitive impairment.

Each participant completed a battery of tasks across two 1.5 hours-long sessions at the lab. Only two of the completed tasks will be reported here. On the first session, participants signed an informed consent form and filled in a demographics questionnaire. Participants then worked on one of two counterbalanced sets of computer-based tasks. Sample size was determined based on the counterbalancing of the order of conditions (memory load; attentional cue; and session order) in a continuous visual WM task performed for the purposes of another study (Souza, 2016).

Materials and Procedure

For the purposes of the present study, participants completed two tasks. The stimuli in these tasks comprised images from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008), which were rated in terms of emotional valence (9-point scale from *most negative* to *most positive*) and arousal (9-point scale from *soothing* to *arousing*). We used the IAPS normative validation ratings to select 183 positive (mean valence = 6.8; mean arousal = 5.1), 183 negative (mean valence = 3.3; mean arousal = 5.1), and 183 neutral images (mean valence = 5.1; mean arousal = 3.4).

We developed a *Serial Image Recognition* (SIR) task to measure the quantity of representations in WM, and the ability to remember item-serial position bindings. In this task, a sequence of 6 images appeared in the middle of the screen, each for 700 ms with a 50 ms inter-image blank interval (see Figure 1a). After the sixth image, a 1-s blank interval followed, after which 16 images appeared on the screen (test display). Participants had to click on the 6 previously shown images in the order they had been presented. A number in the middle of the screen indicated which position within the sequence they were in. Participants completed 24 trials in which all 6 images belonged to the same valence category (single-valence trials; 8 trials per valence), and 24 trials in which 2 positive, 2 negative, and 2 neutral images were randomly shown within each trial (mixed-valence trials). Single-valence and mixed-valence trials were randomly intermixed.

We also developed a *Color-Image Binding* (CIB) task to assess the fidelity (quality) of visual WM representations. This task was adapted from the one reported by Zhang and Luck (2008). Grey-scale images from the IAPS were used as cues and the color frame of each image served as the memoranda. In each trial, three images with a thick colored frame were presented simultaneously for 3 s (see Figure 1b). After a 1-s retention interval, one of the pictures was presented in the middle of the screen (henceforth the target), with a color wheel around it, and the mouse cursor (test display). Participants adjusted the frame-color of the target to match the memorized color for that image. By moving the mouse around the wheel, the target's frame turned into the color in the wheel at the current mouse position. Once sure, participants pressed the left-mouse button to confirm their response. Colors in each trial were sampled randomly from 360 values evenly distributed in the color wheel. Participants completed a total of 150 single-valence trials (50 per valence), and 90 mixed-valence trials. In mixed-valence trials, one image of each valence was shown on the screen for encoding, and at test one image was randomly selected as the target with the constraint that each valence was tested equally often.

Mood was measured before and after the SIR and CIB tasks with the German version of the Profile of Mood States (Dalbert, 1992). Participants also completed the depression items of the trait and state scales of the State-Trait-Angst-Depressions-Inventar (STADI; Laux, Hock, Bergner-Köther, Hodapp, & Renner, 2013).

(Figure 1 about here)

Results

The data and analyses scripts for the reported experiments are available at the Open Science Framework (https://osf.io/4j83a/).

Depression and Mood

Young adults were more state, $t(46) = 3.62$, $p < .001$, and trait depressed, $t(44.7) = 3.46$, $p = .001$, than old adults. For mood, a mixed-design analysis of variance (ANOVA) for each WM task with the variables time (before or after task) and age (young, old) showed that mood got significantly worse after completing each task, SIR: $F(1, 46) = 38.2$, $p < .001$, $MSE = 67.9$, $\eta^2_G = 0.09$; CIB: $F(1, 46) = 28.3$, $p < .001$, $MSE = 60.4$, $\eta^2_G = 0.06$. Moreover, the young were in a significantly worse mood than the older adults in both time points and tasks, SIR: $F(1, 46) = 13.1$, $p < .001$, $MSE = 393.9$, $\eta^2_G = 0.20$; CIB: $F(1, 46) = 14.5$, $p < .001$, $MSE = 390.9$, $\eta^2_G = 0.21$. The two-way interaction was non-significant for both tasks, SIR: $F(1, 46) = 0.01$, $MSE = 67.9$; CIB: $F(1, 46) = 0.09$, $MSE = 60.4$.

SIR Task [1]

Item memory. We computed the proportion of recalled images that belonged to the memory set in each trial irrespectively of serial position – i.e., a free recall score (see Figure 1c). We assessed the effects of age (young, old), trial type (single-valence, mixed-valence), and valence (positive, neutral, negative) on these scores with an ANOVA. There was no evidence for age impairments on item memory, $F(1, 46) = 2.03$, $p = 0.16$, $MSE = 0.08$, $\eta^2_G = 0.04$. Trial type neither yielded a main effect, $F(1, 46) = 0.00$, $p = 0.98$, $MSE = 0.00$, $\eta^2_G = 0.00$, nor significant interactions (all Fs < 1.3, $p > .28$), hence indicating that emotion did not bias encoding in mixed-valence trials. Critically, the main effect of valence was significant, $F(2, 91.9) = 6.70$, $p = 0.02$, $MSE = 0.00$, $\eta^2_G = 0.009$, which was further modulated by an interaction with age, $F(2, 91.9) = 13.60$, $p < 0.001$, $MSE = 0.00$, $\eta^2_G = 0.02$. To follow up on this interaction, we conducted separate

[1] One young participant had one trial with missing values, and another one had 2 additional negative trials at the expense of one neutral and one mixed trial.

ANOVAs for each age group, which showed that the interaction was due to a highly significant valence effect in the old group, $F(1.9, 44.7) = 16.21$, $p < 0.001$, $MSE = 0.00$, $\eta^2_G = 0.08$, but not in the young group, $F(1.84, 42.43) = 0.88$, $MSE = 0.00$. Tests on the least-square means for the valence effect in the old adults showed worse free recall for negative images than neutral, $t(46) = -3.647$, $p = 0.002$, and positive images, $t(46) = -5.611$, $p < 0.001$. Neutral and positive images did not differ from each other, $t(46) = 1.964$, $p = 0.133$.

Binding memory. Next, we calculated the proportion of correctly recalled images at their respective serial position – i.e., a serial recall score (see Figure 1d). Young adults outperformed old adults, $F(1, 46) = 21.37$, $p < 0.001$, $MSE = 0.21$, $\eta^2_G = 0.29$. The main effect of valence just reached significance, $F(1.96, 90.33) = 3.04$, $p = 0.05$, $MSE = 0.01$, $\eta^2_G = 0.002$. Trial type did not have a main effect, $F(1, 46) = 1.22$, $p < 0.280$, $MSE = 0.01$, but there was a trend for an interaction of trial type and valence, $F(1.98, 91.2) = 2.44$, $p = 0.09$, $MSE = 0.00$, $\eta^2_G = 0.001$. All other interactions yielded non-significant results (all *F*s < 1.01, *p*s > .37). Follow up analyses on the valence effect separately in single-valence and mixed-valence trials showed a significant valence effect only in the single-valence trials, $F(1.96, 90.2) = 3.5$, $p = 0.04$, $MSE = 0.01$, $\eta^2_G = 0.006$, but not in mixed-valence trials, $F(1.92, 88.2) = 1.38$, $p = 0.26$, $MSE = 0.00$. Least-square means analyses showed that negative items were worse recalled in single-valence trials than neutral items, $t(92) = 2.397$, $p = 0.048$, and marginally worse than positive items, $t(92) = 2.166$, $p = 0.082$. Positive and neutral images yielded similar performance, $t(92) = -0.231$, $p = 0.971$.

CIB Task

Recall Error. In a first step, a raw recall error score was calculated by taking the absolute distance in degrees on the color wheel between the target color and the reported color. This value ranges from 0° (perfect recall) to 180° (opposite color to the target), and hence smaller values indicate better performance (see Figure 1e). There was trend for an age effect, $F(1, 46) = 3.39$, $p = 0.07$, $MSE = 979.48$, with lower error score for the young compared to old adults. Moreover, there was trend for a valence effect, $F(1.94, 89.08) = 2.53$, $p = 0.09$, $MSE = 66.32$. Least-square means showed that this marginal effect was driven by a trend for positive items to yield lower error than neutral items, $t(92) = -2.117$, $p = 0.092$. Positive items did not differ from negative, $t(92) = -1.712$, $p = 0.206$, and neutral and negative also yielded similar performance, $t(92) = 0.405$, $p = 0.913$. The main effect of trial type did not reach significance, $F(1, 46) = 2.34$, $p = 0.13$, $MSE = 38.36$. The age x valence, $F(1.94, 89.08) = 0.65$, $MSE = 66.32$, age x trial type, $F(1, 46) = 0.46$, $MSE = 38.36$, valence x trial type, $F(2, 91.94) = 0.72$, $MSE = 66.82$, and three-way interactions, $F(2, 91.94) = 0.29$, $MSE = 66.82$, were all very far from significance.

Recall Precision. In a second step, we calculated the reciprocal of the standard deviation of the error (see Figure 1f) to arrive at a measure of recall precision (Bays, Catalao, & Husain, 2009; Peich, Husain, & Bays, 2013) using the code available online at http://www.paulbays.com/code/JV10/index.php. Young adults showed higher precision than old adults, $F(1, 46) = 4.39$, $p = 0.04$, $MSE = 0.42$, $\eta^2_G = 0.06$. Single-valence trials yielded larger precision than mixed-valence trials, $F(1,46) = 4.54$, $p = 0.04$, $MSE = 0.02$, $\eta^2_G = 0.04$. Moreover, there was a marginally significant effect of valence on precision, $F(1.88, 86.59) = 3.0$, $p = 0.06$, $MSE = 0.04$, $\eta^2_G = 0.006$. Comparison of the least-square means for the effect of valence revealed a somewhat larger precision for positive items compared to neutral items, $t(92) = 2.301$, $p = 0.06$. Positive items did not yield better precision than negative items though, $t(92) = 1.883$, $p = 0.14$, and negative and neutral items did not differ, $t(92) = 0.418$, $p = 0.908$. All other interactions were non-significant (*Fs* < 1.5, *MSEs* < 0.07).

Performance Correlations

Table 1 presents correlations between performance in the SIR and CIB tasks for each age group and valence. Performance scores highly correlated across the two tasks (irrespectively of the score derived from it) for the young adults. For the older adults, CIB scores only correlated significantly with free-recall for positive items in the SIR task.

(Table 1 about here)

Discussion

The present study assessed how emotion influences visual WM in young and old adults. First of all, we observed age-related WM impairments. Old adults had difficulties in keeping serial order in visual WM, but showed intact item memory compared to young adults (see also Chee et al., 2006). Moreover, the quality of visual WM representations was lower for old than young adults, replicating recent studies (e.g., Peich et al., 2013). Second, we observed different valence effects across tasks. Negative valence impaired item memory in the SIR task, but only for the old adults. In the CIB task, the image served as a cue to retrieve the precise color of its frame. This task showed a trend for a positivity effect: the color of positive images tended to be reproduced with higher accuracy for both age groups.

Conjointly, these two tasks showed different effects of emotion on WM storage: depending on task requirements emotion could impair or boost performance, reflecting the mixed pattern of findings in the extant literature. The impact of negative content in old age could fit a motivational explanation: Old adults were in a better mood than the young adults, and they might have avoided negative content in the service of emotion regulation goals, which older people seem to prioritize (Mather, 2012). Alternatively, this may represent a quantity-quality trade-off that was only visible for the old adults due to their reduced WM capacity or due to their higher sensitivity to negative content (see point on valence ratings below). This explanation is still viable because an increase in quality could not benefit performance in the SIR task. We evaluated WM quality in the CIB task, but we did not observe evidence for a boost induced by negative content, unlike previous reports using color reproduction tasks and negative-mood induction (Spachtholz, Kuhbandner, & Pekrun, 2014; Xie & Zhang, 2016). Two factors may have prevented the observation of such an effect. First, the possibility remains that negative images were more accurately remembered in the CIB task, but this effect did not extend to the colored-frame of the images. Second, negative content may have increased quality and reduced quantity, but because we only assessed raw scores in this task, we could not properly measure this trade-off. A stronger test of this trade-off can only be done with mixture modeling of the response distributions to decompose the contribution of storage probability and memory precision (Xie & Zhang, 2016; Zhang & Luck, 2008). However, the small number of trials in the present experiment (50 trials per design cell) prevented us from using this approach. What our results allow us to conclude, however, is that this modulation (if existent) did not increase or decrease overall WM performance.

In contrast, positive content improved color recall in the CIB task for both age groups. This trend was not very robust, again possibly due to the relatively small number of trials collected in this task. Future studies may collect larger number of trials (> 100) in each condition to allow for mixture modelling. The modulation by positive items in the CIB task contrasts with the lack of effect in the SIR task. It may be worth noting that participants had a somewhat longer encoding duration (3 s) in the CIB task than in the SIR task, and hence the impact of positive content may take longer to show up. This however was the only condition showing a trend for a true emotional boost on visual WM. Future studies may thus investigate how positive and negative content affects performance over different encoding (and possibly retention) intervals. It may be worth pointing out that participants could not successfully perform the CIB task if they had ignored the images and focused only on their outer frames. This is because, at test, the probe image was presented in the center of the screen thereby removing spatial location as a further retrieval cue to the color. Thus participants had no other cue but the image to attempt retrieval.

Young and old adults did not show opposite modulations by valence. Old adults showed a bias away from negative content, and may preferentially attend to positive content when time is available (as in the CIB task). However, young adults were not biased towards negative content, and they also showed a trend for a positivity effect in the CIB task. Therefore our data is not providing strong support for a positivity bias in old age (Mather, 2012). We selected images from the IAPS based on normative ratings. Ratings for these pictures have been found to differ between age groups (Grühn & Scheibe, 2008): old adults tend to rate negative images as more negative and more arousing than their young counterparts. This may well contribute to the effect of negative content we observed: age group may be confounded with valence and arousal levels, and these two variables may account for the age effect on emotional processing observed here. Relatedly, in the CIB task, the IAPS pictures were presented in greyscale. This may change the overall emotional impact of the images. Note, however, that differential valence ratings and (negative) valence effects on WM have been observed with greyscale images in young adults (Xie & Zhang, 2016). Nevertheless, future studies should collect ratings of the used images to better control for valence and arousal between age groups.

Whereas the young group showed strong correlations between performance of the SIR and the CIB tasks, this was only the case for positive images in the older group. Increases in performance correlations across tasks in old age is the prediction of the age-dedifferentiation hypothesis (e.g., de Frias, Lövdén, Lindenberger, & Nilsson, 2007). This is the opposite of what we observed here. We have no ready explanation for this pattern, but we would like to point out that 24 participants per group can only provide a very noisy estimate of a correlation. Hence it remains open whether this is a reliable finding.

Conjointly, our findings indicated that emotional content modulates visual WM, but this did not provide a differential boost to performance of old adults in our tasks: negative content impaired performance of the older participants increasing the age gap, whereas positive content improved performance similarly across age groups. As such, our results failed to point to emotion as one route to counteract age-related impairments in visual WM.

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Figure Caption

Figure 1. Flow of events in a fictive trial of the Serial Image Recognition (SIR) Task (Panel a) and of the Color-Image-Binding (CIB) Task (Panel b). Panels c and d show free recall and serial recall scores in the SIR task, respectively, as a function of valence, trial type, and age group. Panel e and f show the average recall error and precision of recall, respectively, in the CIB task. Error bars depict the standard error of the mean. *Notes:* pos = positive; neu = neutral; neg = negative. The images used here do not belong to the IAPS.

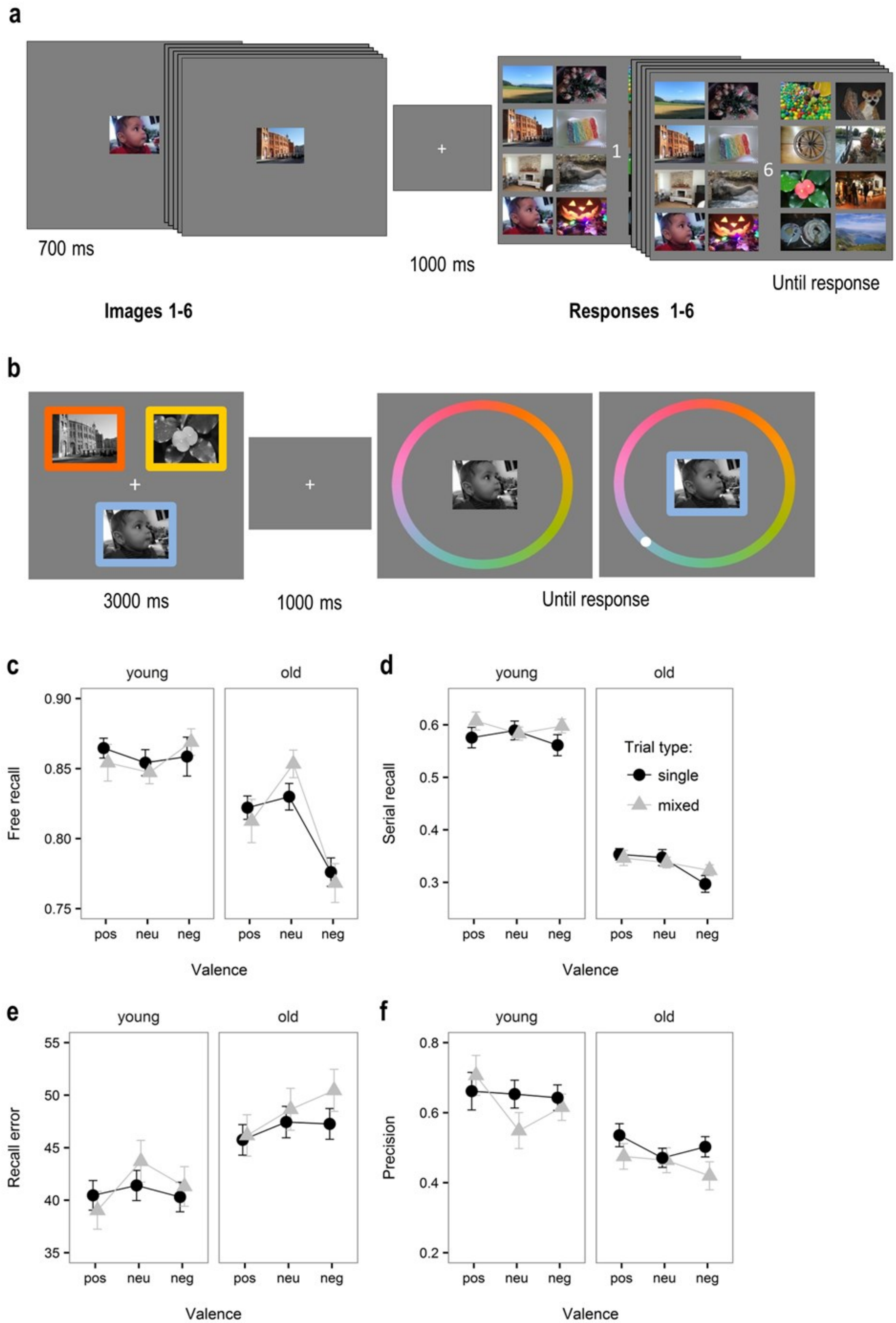
a
1
6
700 ms
1000 ms
Until response
Images 1-6
Responses 1-6
b
3000 ms
1000 ms
Until response
c
young
old
Free recall
0.90
0.85
0.80
0.75
pos neu neg
Valence
d
Serial recall
0.6
0.5
0.4
0.3
Trial type:
single
mixed
e
Recall error
55
50
45
40
35
f
Precision
0.8
0.6
0.4
0.2

Figure 1. Flow of events in a fictive trial of the Serial Image Recognition (SIR) Task (Panel a) and of the Color-Image-Binding (CIB) Task (Panel b). Panels c and d show free recall and serial recall scores in the SIR task, respectively, as a function of valence, trial type, and age group. Panel e and f show the average recall error and precision of recall, respectively, in the CIB task. Error bars depict the standard error of the mean. *Notes:* pos = positive; neu = neutral; neg = negative. The images used here do not belong to the IAPS.

Table 1

Pearson Correlations Between the SIR and the CIB Performance.

		CIB - absolute error			CIB -precision		
		Positive	Neutral	Negative	Positive	Neutral	Negative
SIR scores							
Young	Serial	-0.79***	-0.75***	-0.74***	0.71***	0.72***	0.72***
	Free	-0.72***	-0.83***	-0.76***	0.61**	0.74***	0.72***
Old	Serial	-0.11	-0.32	-0.15	0.07	0.25	0.1
	Free	-0.61**	-0.34	-0.34	0.58**	0.37†	0.34

Note: †$p < .09$ *$p < .05$ **$p < .01$ ***$p < .001$